

Integrating Smartphone-Controlled Paper Airplane Into Gamified Science Inquiry for Junior High School Students

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Abstract

Integrating science learning with game experience and physical manipulatives not only overcomes the rigidity of traditional teaching, but also makes the learning experience pleasant for students and improves their science inquiry ability. Today, with the popularization of mobile devices and technology, both the value and feasibility of gamified science learning have increased significantly. However, several studies showed that students might get lost or feel bored during science inquiry. To let students enjoy the science inquiry process and improve their science process skills, the researchers combined mobile technology, game design elements, and science inquiry and designed the gamified science inquiry activity “we are aircraft designers”. Here, students designed and manipulated a smartphone-controlled paper airplane by mobile devices connected via Bluetooth. To investigate the effects of the gamified science inquiry activity, the flow state and science process skills of 71 students of a junior high school in China were explored. The proposed gamified science inquiry activity enhanced flow and science process skills of students with high and middle level flow. No differences were found on flow and science process skills

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between males and females. Based on these results, the guidelines for the design of a gamified science inquiry activity are discussed.

Keywords

gamification, element of game design, science inquiry, flow, science process skills

Research have emphasized the importance of fostering students' science process skills, which are described as cognitive and investigative abilities involving in the procedure and method of scientific investigations (Gillies & Nichols, 2015; Majeed & Rana, 2018). Indeed, the improvement of science process skills is one of the goals of science education (Afnidar & Hamda, 2015; Majeed & Rana, 2018). Over the past decade, researchers have proposed several methods for the teaching of science process skills. Their research focused on laboratory activities or hands-on activities that were either based on a science inquiry approach (Koksal & Berberoglu, 2014; Lati et al., 2012; Leonor, 2015; Rahmani et al., 2013), a problem-based learning approach (Taşoğlu & Bakaç, 2010; Turiman et al., 2012), an engineering design (Strong, 2013), or a cooperative learning approach (Guevara, 2015; Majeed & Rana, 2018). Among these studies, science inquiry has emerged as an effective learning method that can enhance students' science process skills (Koksal & Berberoglu, 2014; Lati et al., 2012). Science inquiry has been applied for many years, and is still one of the most popular science education teaching methods (Pietarinen et al., 2019; van Riesen et al., 2018).

However, several studies have reported that students might experience a feeling of boredom during science inquiry activities (Hou & Li, 2014). This is particularly the case, when they are faced with intangible concepts (Olympiou et al., 2013), cookbook-based experiments (Hou & Li, 2014), complex situations (Olympiou & Zacharia, 2012), or difficult problems (Manlove et al., 2006) during the science inquiry process. Based on these problems, research has emphasized the importance of integrating games or game design elements into science inquiry activities to facilitate students' learning and keep them engaged in an enjoyable learning process (Squire & Jan, 2007).

Games provide immersive, voluntary, and enjoyable activities where players accomplish challenging goals in accordance with a set of rules (Kinzie & Joseph, 2008). Games also provide an exploratory and interesting environment to access knowledge and develop skills. Over the past decades, several elements of games have been increasingly recognized to be beneficial to learning, in particular, science learning. More and more researchers have emphasized that a game-based learning approach can not only improve students' learning experience, but also foster the development of higher order knowledge and skills (Sánchez &

Olivares, 2011; van Eck, 2007). With the rapid development of mobile technology, mobile devices and associated educational applications are increasingly being used in elementary and secondary schools already (Kearney et al., 2015). Mobile devices offer many advantages, such as powerful computing power, portability, wireless communication capabilities, and context-awareness (Zydney & Warner, 2016). Because of these advantages, mobile devices can provide students with a rich science environment and an immersive learning experience for science learning (Bano et al., 2018). It has also been observed that the application of mobile technology offers the potential to improve students' inquiry abilities and enhance their procedural knowledge (Falloon, 2017; Song, 2016).

According to the above background, the researchers designed a gamified science inquiry activity, which is supported by mobile technology, science inquiry, and game design elements. Its implementation is expected to encourage students to engage in the gamified inquiry process, while improving their science process skills at the same time. In addition, flow is considered to be an individuals' psychological state of full engagement with an activity (Csikszentmihalyi & Csikszentmihalyi, 1988). Moreover, flow has been identified as a useful tool to examine the engagement of students and to assess the quality of the game design (Bressler & Bodzin, 2013; Kiili et al., 2012). Research has shown that the flow state can predict the motivation of students and enables them to achieve higher levels of performance (Hsu & Lu, 2004; Inal & Cagiltay, 2007; Pearce et al., 2005). Therefore, flow and the improvement of science process skills at different flow levels were explored in a gamified science inquiry activity. Moreover, research in the literature has also shown that males are more active and motivated in both science (Riegler-Crumb & King, 2010; Rozek et al., 2015) and games (Paaßen et al., 2017) than females. Consequently, potential gender differences in the improvement of flow and science process skills have also been investigated in this study. The effectiveness of the proposed approach was investigated by the following research questions:

1. How can the proposed gamified science inquiry activity promote students' flow?
2. How can the proposed gamified science inquiry activity improve students' science process skills?
3. How can the proposed gamified science inquiry activity improve the science process skills of students with different levels of flow?
4. How do gender differences affect the flow of students in the proposed gamified science inquiry activity?
5. How do gender differences affect the science process skills of students in the proposed gamified science inquiry activity?

Literature Review

Gamification and Science Inquiry

Gamification refers to the use of game design elements in non-game contexts with the goal to engage people and solve problems (Deterding et al., 2011). Commonly used game design elements include goals, rules, storyline, interactivities, competition, feedback, fantasy, safety, rewards (e.g., badges and points), and challenges (Aldemir et al., 2018; Hamari et al., 2014). In recent years, various studies combined science inquiry with gamification and explored the effectiveness of this approach. For example, Jacobson et al. (2016) developed a “game-like” virtual world based on a computational scientific inquiry approach so that students can virtually experience biological fieldwork. The results indicated that this approach exerted a positive impact on the science inquiry skills of students in an eighth-grade class (Jacobson et al., 2016). Tsai (2018) developed a computer-simulated science inquiry environment, named the Science Detective Squad. It integrated game design elements (i.e., points and story-based tasks) as a scaffold and feedback mechanism, and guided students through investigating an electricity problem. The authors found that students’ electricity knowledge and perceptions about the environment were significantly increased after this activity (Tsai, 2018). Overall, with game design elements as components, a game approach not only resulted in an engaging and enjoyable inquiry process, but also improved knowledge and inquiry skills.

Mobile Learning and Science Inquiry

With the development and popularization of mobile technology, both researchers and educators identified the educational value of mobile technologies for science learning. The advantages mobile technology offers, such as portability, connectivity, flexibility, computing power, and ease of access, have significantly contributed to science learning, especially science inquiry (Bano et al., 2018; Looi et al., 2015; Suárez et al., 2018). Because of these advantages, mobile technology can facilitate rich learning environments, offering for example, procedural guidance (Fu & Hwang, 2018), dynamic learning context and materials (Zhai et al., 2019), immediate feedback (Hung et al., 2013), data collection and analytic tools (Zuiker & Wright, 2015), as well as social communications tools (Song, 2016) for the science inquiry process. Recently, it has been indicated that science inquiry supported by mobile technology exerts positive effects on knowledge acquisition, motivation, decision making, and higher order thinking skills. For example, Chen and Lin (2016) designed a context-aware astronomy learning system, which integrated radio frequency identification, wireless communication network, mobile devices, and databases to help students identify stars and constellations. The results indicated that this context-aware astronomy learning

system can help to improve both the acquisition and retention of knowledge (Chen & Lin, 2016). Hsiao et al. (2016) developed a manipulative augmented reality system for the learning of the unit “Understanding Weather” in a natural science course. The manipulative augmented reality system combined three-dimensional interactive models and manipulative aids. The results showed that using this manipulative augmented reality system for an inquiry-based field study positively impacted both students’ academic achievement and motivation (Hsiao et al., 2016). Choi et al. (2018) implemented a mobile application, which supports students to identify the tree life cycle by using problem-solving strategies. Their results indicated that the mobile learning experience and its external representations helped students to engage in deep learning, use decision making strategies, and solve problems within the natural setting (Choi et al., 2018).

Gamified Science Inquiry with Mobile Technology

According to the above literature review, it can be concluded that mobile technology offers the potential to support the science inquiry process by providing procedural support, learning resources, and auxiliary tools. Furthermore, gamification can make the science inquiry process enjoyable, interesting, and immersive. However, despite the claims of the literature, which propose that game design techniques should inform the design of science inquiry activities, research has not provided relevant empirical evidence.

Boticki et al. (2015) designed a mobile learning system and named it SamEx, which supports self-directed and collaborative learning activities. SamEx applies a badge system to encourage participation through the inquiry process, and also question prompts as scaffolding based on the time and location of users (Boticki et al., 2015). The results indicated that both the quantity and quality of students’ contributions in SamEx could be used to predict the assessment score. In addition, contextual answers and overall badges received by students also correlated with the assessment score (Boticki et al., 2015). Su and Cheng (2015) designed a series of gamified learning activities based on the mobile gamification learning system. Their results showed that integrating context-aware technology and gamification method into a botanical learning process resulted in higher learning achievement and motivation (Su & Cheng, 2015).

The above analysis indicates that research regarding the integration of gamification, mobile technology, and science inquiry primarily focused on learning outcomes, such as learning achievements and motivation. Far less research has addressed the learning process and the attained improvement of skills (Li & Tsai, 2013). Many researchers have focused on mobile science inquiry games (e.g., Bressler & Bodzin, 2013; Squire & Jan, 2007) rather than on mobile gamified science inquiry activities. Therefore, this study investigated the effects

of a gamified science inquiry activity, supported by mobile technology, on the improvement of skills and learning process, i.e., flow and science process skills.

Flow refers to an optimal experience of individuals where they are very deeply involved with the activity so that nothing else seems to matter (Csikszentmihalyi, 1975, 1991). Flow often occurs when people enter a psychological state of full engagement with an activity (Csikszentmihalyi & Csikszentmihalyi, 1988). Therefore, flow can be used to investigate students' gameplay experience (Csikszentmihalyi, 1975) and also to investigate the quality of the game design. In this study, flow incorporates two indicators: flow antecedent and flow experience. Flow antecedents are game design elements that contribute to the initiation of a flow state in the player (Kiili & Lainema, 2008). Examples are challenge/skill balance, clear goal, immediate feedback, playability, gamefulness, frame story, and peer interaction. Flow experience, on the other hand, represents the psychological state of total involvement in an activity (Csikszentmihalyi, 1991), which includes concentration, sense of control, loss of time and self-consciousness, as well as autotelic experience. A further aim of this study was to investigate the improvement of science process skills.

Science process skills are related to cognitive skills (i.e., inquiry skills and problem solving skills) and reflect how scientists think about and conduct their research (Lin et al., 2018; Shahali et al., 2017). The present study focused on science process skills, which are based on the cycle of science inquiry (Bourdeau & Arnold, 2009). The aim of this study was to investigate critical steps of the complete inquiry process. Based on relevant literature, the science process skills to be investigated in this study include forming scientific questions, designing scientific procedures, collecting and recording data, analyzing results, using models to describe results, and creating scientific presentations (Bourdeau & Arnold, 2009).

Methodology

Activity Design

The researchers designed the gamified science inquiry activity 'we are airplane designers' by integrating game design elements, mobile technology, and inquiry learning. The gamified science inquiry activity utilized the smartphone-controlled paper airplane Power Up 3.0. Power Up 3.0 can be installed on a paper plane, which students can design themselves. Students can manipulate Power Up 3.0 by connecting it with the respective smartphone application via Bluetooth technology. Based on the gamified science inquiry activity and Power Up 3.0, students can acquire flight knowledge and learn relevant principles. These include the components and functions of the aircraft, the basic flight principle of the aircraft, the causes affecting the flight (lift), the relationships underlying the aircraft lift, and the aircraft structure.

As shown in Figure 1, the gamified science inquiry activity includes a number of game design elements, such as characters and avatars, storyline, sociality, fantasy, sensory stimulation, game progress, feedback (e.g., rewards and badges), rules, goals, and challenges.

The gamified science inquiry activity was designed based on the inquiry cycle of Llewellyn (2005). The following six tasks were designed: 1. introducing the aim of the activity and forming a flight design team, 2. designing the aircraft structure, 3. testing the flight performance of the designed aircraft, 4. improving the aircraft structure and re-testing its flight performance, 5. analysis of flight data, 6. sharing and exchange of scientific research results. These tasks were designed in the gamified science inquiry activity based on a six-step inquiry cycle (inquisition, acquisition, supposition, implementation, summation, and exhibition). The six stages of the gamified science inquiry activity are shown in Figure 2.

Characters and avatars	Characters in the gamified science inquiry activity included: one chief engineer, two associate engineers, and five aircraft designers. Lists of tasks exist for every character in the gamified science inquiry activity.
Goals and storyline	The storyline and goal of this activity are: the space agency had difficulties to design the aircraft. They invite students to overcome five scientific problems, and ultimately to design a plane with good flight performance. The team that accomplishes the tasks successfully and quickly will become the “Top Aircraft Design Team”. There are five sub-goals and storyline in every sub-activity.
Sociality	Competition: Teams compete to be the “Top Aircraft Design Team” and receive a prize. Cooperation: Seven or eight students corporate and accomplish six tasks.
Fantasy, sensory stimulation	Students use a smart phone to control the flight of the paper aircraft via Bluetooth similar to a real pilot since they can control the aircraft to ascend, descend, turn left, turn right, accelerate, and decelerate. The smart phone provides students a simulated flight window and also provides a more realistic flight experience for them.
Game progress	There are six tasks in the gamified science inquiry activity. The activity progress and the badges of each team will be displayed before the next task.
Feedback (e.g., rewards, badges)	Students receive star badges after completing a task. After completing all tasks, the team with the most badges will be named “Top Aircraft Design Team” and win a prize.
Rules	There are six tasks (from activity 1 to activity 6). Each time a task is completed, the next activity sheet can be received. The teacher presents star badges to each team based on the quality of their work.
Challenges	Six science tasks within the activity are challenges.

Figure 1. Game Design Elements of the Gamified Science Inquiry Activity.

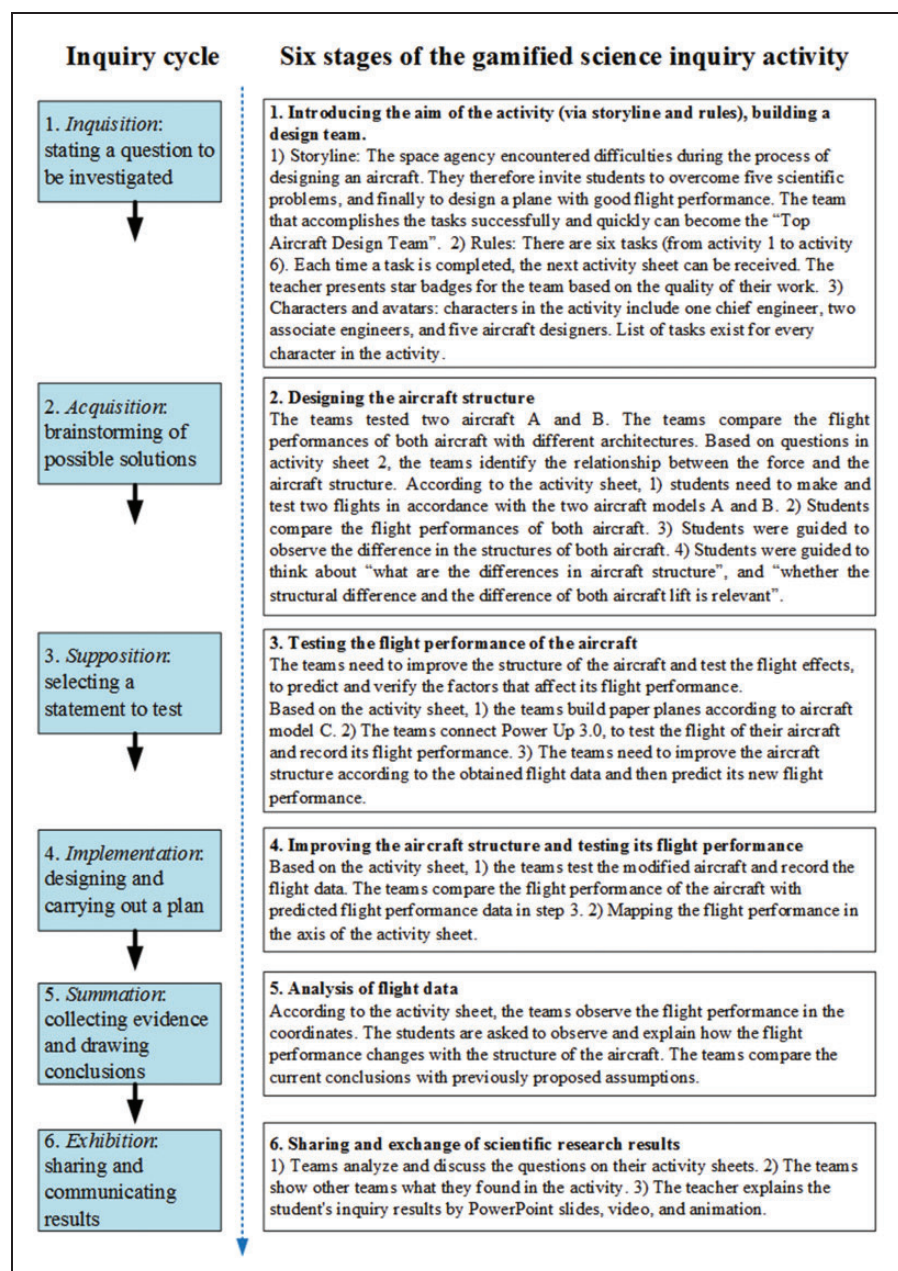


Figure 2. Processes of the Gamified Science Inquiry Activity.

Participants

Two eighth-grade classes from a junior high school located in East China were involved in this study after contacting and obtaining the permissions of school director and teacher. The students were composed of 71 eighth grade students aged from 14 to 15 years (31 males and 40 females). All students had learned the requisite prior knowledge of physics and their age presents an important time for enhancing science process skills (Bourdeau & Arnold, 2009). Participants were randomly assigned either to an experimental group or a control group. The control group included a total of 35 participants (16 males and 19 females) and the experimental group included a total of 36 participants (15 males and 21 females). The experimental group was guided by the gamified science inquiry approach while the control group was guided by a multimedia-based approach. Both the experimental and the control groups had the same teacher during the experiment.

Measurement

The research tools included questionnaires for measuring students' "science process skills" and "flow". The questionnaire for science process skills was adopted from that developed by Bourdeau and Arnold (2009), since it offered a good fit for both the participants as well as the aim of this study. The questionnaire was designed for middle school students of ages 12 and older, which covered the participants of this study. Furthermore, the questionnaire was developed to measure the range of skills regarding the cycle of science inquiry that was investigated in this study. The questionnaire consisted of 11 items with a four-point rating scheme and mirrored the steps of the science inquiry process. The following skills were included: forming scientific questions, designing scientific procedures, collecting and recording data, analyzing results, using models to describe results, and creating scientific presentations. The Cronbach's alpha value of the questionnaire was 0.91.

This study adopted the flow scale of Zheng and Spires (2014) because it included peer interaction indicator. This study involved various roles in the gamified activity, and was a face-to-face collaborative game playing activity. The questionnaire consisted of 36 items with a five-point rating scheme. It consisted of two dimensions: 15 items for "flow experience" and 21 items for "flow antecedent". The Cronbach's alpha values of the questionnaire, flow experience, and flow antecedent were 0.96, 0.93, and 0.94, respectively.

Experimental Procedures

Figure 3 shows the procedure of the experiment. Prior to the learning activity, both the experimental group and the control group completed a science process skills questionnaire. During the learning activity, the students of the experimental group

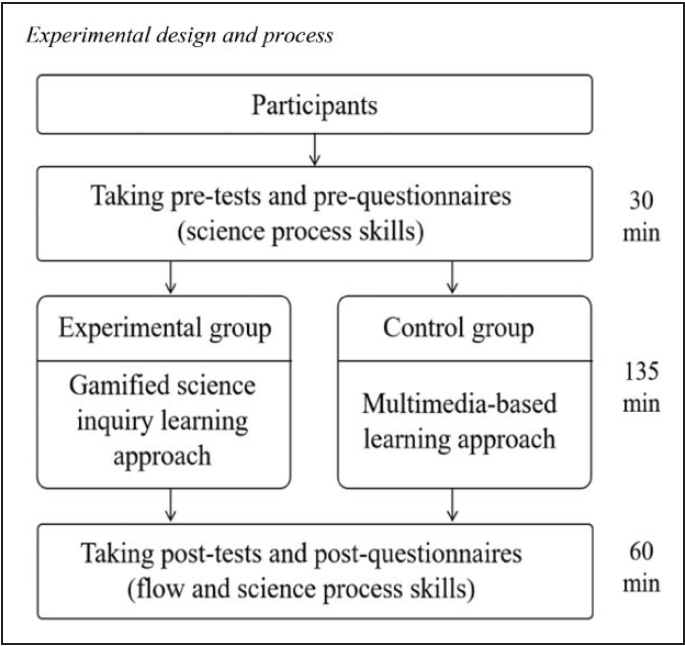


Figure 3. Experimental Design and Process.

learned with the gamified science inquiry learning approach. The students of the control group learned with the multimedia-based learning approach, in which the teacher guided students to investigate the learning theme (i.e., how to design a plane with good flight performance). Students learned by using multimedia learning materials (with the same learning theme as the experimental group) prepared in advance. These materials included PowerPoint slides, videos, and animations, and students were asked to complete a learning sheet and report their findings about the learning theme. The same questions of the learning sheet were used during the last step of the experimental or control treatment. The teacher then provided further explanations on students' findings so that students could achieve a comprehensive and deep understanding of the learning theme. Both experimental group and control group had 135 min to carry on their learning activities.

After the learning activity, both experimental group and control group completed the science process skills and flow scale questionnaires to report any changes in their science process skills and flow.

Data Analysis

Changes in student science process skills between the experimental and control groups were compared by using ANCOVA to determine if the two groups

Table 1. Descriptive Data and ANCOVA of the Post-Test Results.

Group	N	M	SD	Adjusted mean	Std. error	F
Experimental Group	36	29.92	4.98	30.06	.94	2.288
Control Group	35	28.20	6.78	28.05	.95	

showed significant differences in their science process scores. The statistical analysis used pre-test scores as covariate and post-test scores as dependent variables. Moreover, the differences in flow between the experimental and control groups were analyzed by using a *t*-test to explore whether the two groups showed significant differences in flow test scores.

To investigate the effectiveness of the proposed gamified activity on the improvement of the science process skills of students with different levels of flow, the Wilcoxon Matched Pairs Signed Rank test was used to compare pre-test and post-test science process skills of the low-level flow group, the middle-level flow group, and the high-level flow group. In addition, this study explore how the gender of students affected the science process skills or flow in the proposed gamified science inquiry activity. The Mann-Whitney U test was used to assess the differences in the pre-test science process skills and flow between males and females.

Results

Analysis of Science Process Skills

The homogeneity test of regression coefficients showed that the pre-test scores of the experimental group and control group were homogeneous ($F = .003$, $p = .954$), indicating that ANCOVA could be applied further. As shown in Table 1, the adjusted mean values of the post-test scores were 30.06 for the experimental group, and 28.05 for the control group. Furthermore, there was no significant difference between the experimental group and the control group ($F = 2.288$, $p = .135$).

Analysis of Flow

Table 2 shows the *t*-test results of the students' flow between experimental and control groups. The mean values and standard deviations of flow were 134.14 and 17.91 for the control group, and 158.61 and 16.43 for the experimental group. These results indicated a significant difference ($t = 6.003$, $p < .001$, Cohen's $d = 1.42$) between both groups. Furthermore, the effect size (d) was 1.42, which indicated a very large effect (Sawilowsky, 2009). This means that students who learned in the proposed gamified science inquiry activity achieved

Table 2. T-Test Result of Flow Between Control Group and Experimental Group.

Factors	Group		t	p	95% CI for mean difference	Cohen's d
	Experimental group (n = 36) M (SD)	Control group (n = 35) M (SD)				
Flow antecedents	90.83 (11.34)	78.17 (10.16)	4.951	<.001***	7.560, 17.764	1.18
Flow experience	67.78 (6.10)	55.97 (8.52)	6.731	<.001***	8.307, 15.305	1.59
Sum	158.61 (16.43)	134.14 (17.91)	6.003	<.001***	16.337, 32.600	1.42

*** $p < .001$.

significantly higher flow than students who learned in the multimedia-based learning activity. It was therefore inferred that the proposed gamified science inquiry activity was better able to engage students.

Furthermore, as shown in Table 2, significant differences were found in the flow antecedent ($t = 4.951$, $p < .001$, Cohen's $d = 1.18$) and the flow experience ($t = 6.731$, $p < .001$, Cohen's $d = 1.59$). This indicates that game design elements (such as challenge/skill balance, clear goal, immediate feedback, playability, gamefulness, frame story, and peer interaction) were well-designed and provided students with a joyful experience. Furthermore, the proposed gamified science inquiry activity created an engaging environment where students entered the psychological state of total involvement with the activity.

Analysis Science Process Skills with Different Levels of Flow

As shown in Table 3, for the low-level flow group, the mean values and standard deviations were 28.17 and 4.47 for post-test scores, and 26.75 and 3.22 for pre-test scores, respectively. There was no significant increase ($Z = -1.114$, $p = .265$, $r = -0.179$) in the science process skills in the low-level flow group. For the middle-level flow group, the post-test scores ($M = 30.25$, $SD = 4.94$) were significantly higher than the pre-test scores ($M = 27.67$, $SD = 4.42$) ($Z = -2.052$, $p = .040$, $r = -0.265$). The effect size value was $r = -0.265$, which indicated an intermediate effect size, further indicating that the difference of science process skills between pre-test and post-test scores was significant. For the high-level flow group, the post-test scores ($M = 31.33$, $SD = 5.38$) were significantly higher than the pre-test scores ($M = 25.67$, $SD = 5.12$) ($Z = -2.005$, $p = .045$, $r = -0.474$). The effect size value was $r = -0.474$, which indicated a large effect size. This indicated that the difference of science process skills between pre-test and post-test scores was significant. Therefore, this result implied that

Table 3. Wilcoxon Matched Pairs Signed Rank Test Results of the Science Process Skills of Different Flow Levels.

Level of flow	<i>n</i>	Pre-test <i>M</i> (<i>SD</i>)	Post-test <i>M</i> (<i>SD</i>)	<i>Z</i>	<i>p</i>	<i>r</i>
Low-level flow	12	26.75 (3.22)	28.17 (4.47)	−1.114	.265	−0.179
Middle-level flow	12	27.67 (4.42)	30.25 (4.94)	−2.052	.040*	−0.265
High-level flow	12	25.67 (5.12)	31.33 (5.38)	−2.005	.045*	−0.474

**p* < .05.

Table 4. Mann–Whitney U Test Results of Post Science Process Skills Scores Between Genders in the Experimental Group.

	Group		<i>U</i>	<i>Z</i>	<i>p</i>	<i>r</i>
	Males (<i>n</i> = 15) <i>M</i> (<i>SD</i>)	Females (<i>n</i> = 21) <i>M</i> (<i>SD</i>)				
Pre-test	26.13 (4.53)	27.10 (4.16)	104.500	−0.548	.590	−0.111
Post-test	29.67 (5.53)	30.10 (4.69)	152.000	−0.178	.874	−0.042

the proposed gamified science inquiry activity enhanced the science process skills of students with high- and middle-level flow.

Analysis of Science Process Skill Differences between Males and Females

The results showed that, prior to the gamified science inquiry activity, the mean values and standard deviations of science process skills were 26.13 and 4.53 for males, and 27.10 and 4.16 for females, respectively. This result indicated no significant difference of pre-test scores of science process skills (*U* = 104.500, *Z* = −0.548, *p* = 0.590, *r* = −0.111) between males and females before the proposed gamified activity. As shown in Table 4, after the gamified science inquiry activity, the mean values and standard deviations of science process skills were 29.67 and 5.53 for males, and 30.10 and 4.69 for females. There was no significant difference of post-test scores of science process skills (*U* = 152.000, *Z* = −0.178, *p* = 0.874, *r* = −0.042) between males and females after the proposed gamified activity. These results indicated that the proposed gamified science inquiry activity caused no significant difference in the science process skills between males and females.

Analysis of Flow Difference Between Males and Females

As shown in Table 5, the mean and standard deviation of the flow scores achieved by males were 153.67 and 14.43, respectively, while those achieved

Table 5. Mann–Whitney U Test Results for Flow of Gender in the Experimental Group.

Factors	Group		<i>U</i>	<i>Z</i>	<i>p</i>	<i>r</i>
	Males (<i>n</i> = 15) <i>M</i> (<i>SD</i>)	Females (<i>n</i> = 21) <i>M</i> (<i>SD</i>)				
Flow antecedents	88.13 (9.13)	92.76 (12.53)	117.000	−1.303	.202	−0.207
Flow experience	65.53 (6.24)	69.38 (5.59)	102.000	−1.787	.077	−0.309
Sum	153.67(14.43)	162.14 (17.18)	109.500	−1.554	.125	−0.258

by females were 162.14 and 17.18, respectively. These results indicated no significant difference ($U=109.500$, $Z=-1.554$, $p=.125$, $r=-0.258$) of flow between males and females. With regard to the flow experience, the mean and standard deviation of the flow experience achieved by males were 65.53 and 6.24, respectively, while those achieved by females were 69.38 and 5.59, respectively. The results indicated no significant difference ($U=102.00$, $Z=-1.787$, $p=.077$, $r=-0.309$) of the flow experience between males and females. While the mean and standard deviation of the flow antecedent achieved by the males were 88.13 and 9.13, respectively, those achieved by females were 92.76 and 12.53, respectively. These results indicated no significant difference ($U=117.000$, $Z=-1.303$, $p=.202$, $r=-0.207$) of flow antecedent between males and females. Therefore, the proposed gamified science inquiry activity exerted no significant difference on flow between males and females.

Discussion

Flow

This study investigated a gamified science inquiry activity supported by mobile technology. The results showed that the proposed gamified science inquiry activity improved students’ flow. The results further showed that the science process skills of students with high and middle levels of flow showed significant improvement after the proposed gamified activity. No differences were found for flow and science process skills between males and females in the proposed gamified science inquiry activity.

These findings, to some extent, support previous research, emphasizing that well-designed gamified activities could boost the flow experience and engagement of students (Kiili et al., 2012; Perttula et al., 2017). Csikszentmihalyi (1997) also indicated that flow experiences occur when the game balances game challenge and students’ skills. Furthermore, game design elements (i.e., challenge/skill balance, clear goals, unambiguous feedback, time pressure, and social game mechanics) have been found to facilitate to flow (Perttula et al., 2017). The

results identified a significant difference in flow between the experimental group and the control group. This further indicated that the students engaged in the gamified science inquiry activity which kept the balance between game challenge and students' skills. Moreover, the results also indicated that the game design elements of the proposed activity (such as game goals, rewards, and storyline) met the students' preference. Therefore, it can be concluded that the proposed gamified science inquiry activity was generally well-designed and engaged students in a joyful manner.

Science Process Skills and Different Levels of Flow

Although the above-presented results indicated that the proposed gamified activity can generally engage students compared with a multimedia-based group, it could not achieve the same engagement for all students in the experimental group. Students may experience different levels of flow for a gamified activity because of various game preferences (Inal & Cagiltay, 2007; Kinzie & Joseph, 2008) and skills levels (Csikszentmihalyi, 1997). In the meanwhile, research showed that the flow state impacted learning though intrinsic motivation (Linnenbrink & Pintrich, 2002; Malone & Lepper, 1987), which thus enabled learners to achieve higher levels of performance (Pearce et al., 2005). That is why the effects of different levels of flow on the science process skills was analyzed. The results of research questions 2 and 3 indicated the effect of different levels of flow on the science process skills.

There was no significant difference on science process skills between the gamified science inquiry activity and the multimedia-based activity. However, when exploring the science process skills of students with different levels of flow in the gamified activity, students with high and middle levels of flow showed significant improvements in their science process skills. These findings were in line with Hsieh et al. (2016), who reported that students with higher flow experiences tend to have higher learning performances (Hsieh et al., 2016). Furthermore, flow and enjoyment have been suggested to directly affect learning, or to potentially also increase the intrinsic motivation of students, thus further involving them in learning tasks (Linnenbrink & Pintrich, 2002; Meyer & Turner, 2006). Students with high levels and middle levels of flow may consider their experience to be enjoyable and successful in the gamified activity. Positive emotions may motivate students to continuously attempt further challenges and complex tasks in the gamified science inquiry activity. Furthermore, the acquisition and improvement of skills require long-term learning and practice. Research showed that students require lengthy training to develop, refine, and polish their inquiry ability (Hardianti & Kuswanto, 2017). Continued practice in the proposed gamified activity enhanced the understanding of how to conduct a science inquiry activity for students with higher levels of flow. This increased the likelihood of science process skill improvement. This may explain

why the proposed gamified science inquiry activity enhanced the science process skills of students with high and middle levels of flow.

For students with low levels of flow, the proposed activity did not offer different challenges, designed according to different skill levels. Flow does not occur when the game cannot retain the balance between students' skills and challenge levels, i.e., either when the game is too easy and hence boring, or too difficult and hence frustrating (Csikszentmihalyi, 1991; Inal & Cagiltay, 2007; Kinzie & Joseph, 2008). These passive emotions can become obstacles for the involvement in the activity and can negatively impact the attempted challenge (Linnenbrink & Pintrich, 2002; Meyer & Turner, 2006). Gultepe and Kilic (2015) indicated that notable improvements of experimental skills cannot be expected after only a few operations or practicing a few times only. Students with low levels of flow could not fully engage in the gamified science inquiry activity. They were not motivated to reflect and discuss the inquiry process and results, or to obtain a deep understanding of inquiry methods and processes. This may be the reason for the lack of improvement of science process skills by students with low levels of flow.

Gender in Science Process Skills and Flow

Gender has always been an important variable in game-playing and science learning (Bressler & Bodzin, 2013). The proposed activity integrated science inquiry, gamification, and technology, two of which (i.e., motivation for science and attitude toward gaming) have been considered as male-dominated fields. Therefore, the expectation is that gender can predict flow and science process skills. However, recent research showed that females today account for half of the gaming population (Lopez-Fernandez et al., 2019; Paaßen et al., 2017; Spieler & Slany, 2018), and are also increasingly involved in science learning and technology. Therefore, this topic may require further investigation. This study found no significant differences for flow and science process skill between males and females. The proposed gamified science inquiry activity achieved equal engagement and effectiveness for males and females. For flow, equal engagement may correlate with the gamified design. Females and males expect different components or game design elements from computer games (Inal & Cagiltay, 2007). For example, males emphasized rules-based, winning games, and dealt with challenges (Gómez-Gonzalvo et al., 2020; Inal & Cagiltay, 2007), while females preferred stories (Inal & Cagiltay, 2007; Spieler & Slany, 2018). The proposed activity engaged both males and females equally because it involved comprehensive and diverse game design elements. Therefore, it equally appealed to both males and females. The activity exerted the same effectiveness on science process skills for males and females. Yamtinah et al. (2017) reported that males and females were not different with regard to science process skills. Furthermore, males achieved better results for observation, controlling variable,

and conclusion making, while females were better in conceptual knowledge and interpretation (Yamtinah et al., 2017). These indicators were not explored in this study. Therefore, nothing can be concluded about sub indicators.

Implications

This study identified various educational implications for the design of gamified science inquiry activities were identified in this study. First, integrating science inquiry, mobile technology, and gamification is an effective method to improve students' flow, and, to some extent, enhance students' science process skills. Several studies indicated that motivation and flow are positively related (Chang et al., 2012; Inal & Cagiltay, 2007). Furthermore, enhancing the motivation of scientific learning is also one of the important goals of science education. Therefore, the proposed gamified science inquiry method is worthy of being generalized for other applications. The guidelines for the design of a gamified science inquiry activity used in this study are summarized in the following: 1) Identify the inquiry problem, and divide the inquiry problem into several sub-questions according to the inquiry process. 2) Design goals of gamified science inquiry activity for every inquiry sub-question. Set multiple paths to the goals of the gamified science inquiry activity. 3) Set goals and paths toward these goals into a storyline and situation. Design characters and tasks for different situations. 4) Design rules for every activity goal, such as setting evaluation criteria, time limit, and quality of tasks. The aim of rule setting is to build challenges into the gamified inquiry activity. Therefore, it is necessary to balance challenging activities and required skills. The challenge should neither be too easy nor too difficult to achieve. 5) Integrate competition, cooperation, or rewards into the activity. Rewards can be points, badges, or tools for follow-up activities. 6) Integrate with mobile devices as inquiry tools, such as tools for data searching or measurement tools via sensors, augmented reality technology, and information retrieval technologies.

Second, different and progressive challenge levels, as well as multiple game design elements should be integrated into the design of the gamified science inquiry activity. The gamified activity introduced in this study could not attract all students and keep them engaged all the time, because it has not been designed to offer a different level of challenge for all students participating in the activity. To facilitate the achievement and maintenance of engagement, and further enhance science process skills, challenge-skill balance and progressive level of difficulty are two important facets educators should pay more attention to. Furthermore, utilizing multiple game design elements was a good way to reduce the gender difference. When designing a gamified activity, it is necessary to consider the expectations of both genders.

This study had several limitations. First, the number of participants was small. This specific target group limits the generalizability of the results.

Second, the proposed activity period was short. Furthermore, seven to eight students cooperated in the gamified science inquiry activity; therefore, practices and operations contributed by each student were relatively small. Therefore, a short period of activity and limited practice of process skills did not reveal the effectiveness of the activity. Last, the proposed gamified activity did not have progressively more challenging levels according to different skill levels. Therefore, it could not engage all students and keep them absorbed all the time. Future research should use a series of gamified scientific inquiry activities to explore their effectiveness. Second, different challenge levels should be designed according to the skills of different students. Third, students' behavior patterns and science discourse need to be assessed for a deeper understanding of the gamified science inquiry process. For example, it remains to be explored how students acquire science process skills and construct science concepts during the gamified science inquiry activity.

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